

Structured Approaches to Decision Making for Cleaner Products and Processes

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Introduction

The development of Cleaner Products and Processes (CPP) is consistent with our drive towards Sustainability. The development of CPP initiatives requires an understanding of the context in which we seek to apply these. We need an objective method by which to assess whether a given initiative will really deliver the benefits anticipated. This requires that we be able to assess CPP initiatives in terms of **technical feasibility**, and **economic, environmental and social benefits**.

A Structured Approach to CPP Assessment

We argue that the evaluation of CPP initiatives should be informed by “Life Cycle Thinking”, the practice of which is embodied in **Life Cycle Assessment (LCA)**.

*“..aims to provide the basis for **decisions** which promote **sustainable development** of our **economies**”*

LCANet, 1997

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CPP and EMS

- LCA now included in EMS standards (ISO 14040,14041,14042 and 14043.)
- LCA can be used to inform EIAs of new projects – and identification of CPP opportunities
- EMSs provide framework for reporting, monitoring, and general data management to assess CPP initiatives
- LCA supported EMSs can direct continuous improvement – a CPP objective – by empowering companies to target points of intervention within their control to improve “base line” environmental performance.

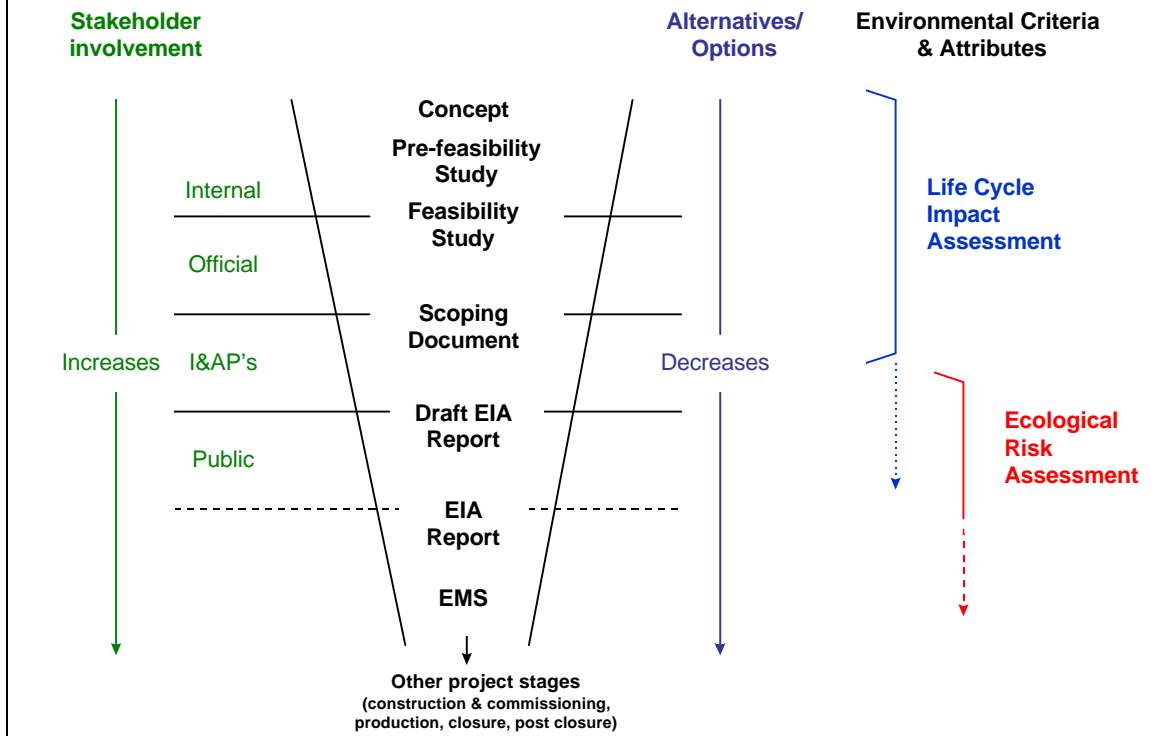
CPP Decision Levels

Level	Type	Example
Operational	• Operational Management	Compliance with legislation, environmental management, supplier choice, etc.
	• Communication & Marketing	Marketing decisions, eco-labelling, environmental reporting, etc.
Tactical	• Design & Development	Product development, process development, technology development, etc.
Strategic	• Capital Investments & Acquisition	Investment in new technology or production line, acquiring another company, etc.
	• Strategic planning	Policy development, strategies for development of new technology, strategies for R&D, etc.

Decision Context

- Strategic Decisions & Decisions During Early Stages of a Project Life Cycle
 - Large number of alternatives (strategies)
 - Large degree of uncertainty
 - Large spatial and temporal scales or no site specificity
 - Stakeholder involvement often indirect
- Tactical Decisions & Decisions During Later Stages of a Project Life Cycle
 - Fewer alternatives
 - Less uncertainty
 - Site specificity
 - Stakeholder involvement often direct

Decision Support during Project Life Cycle

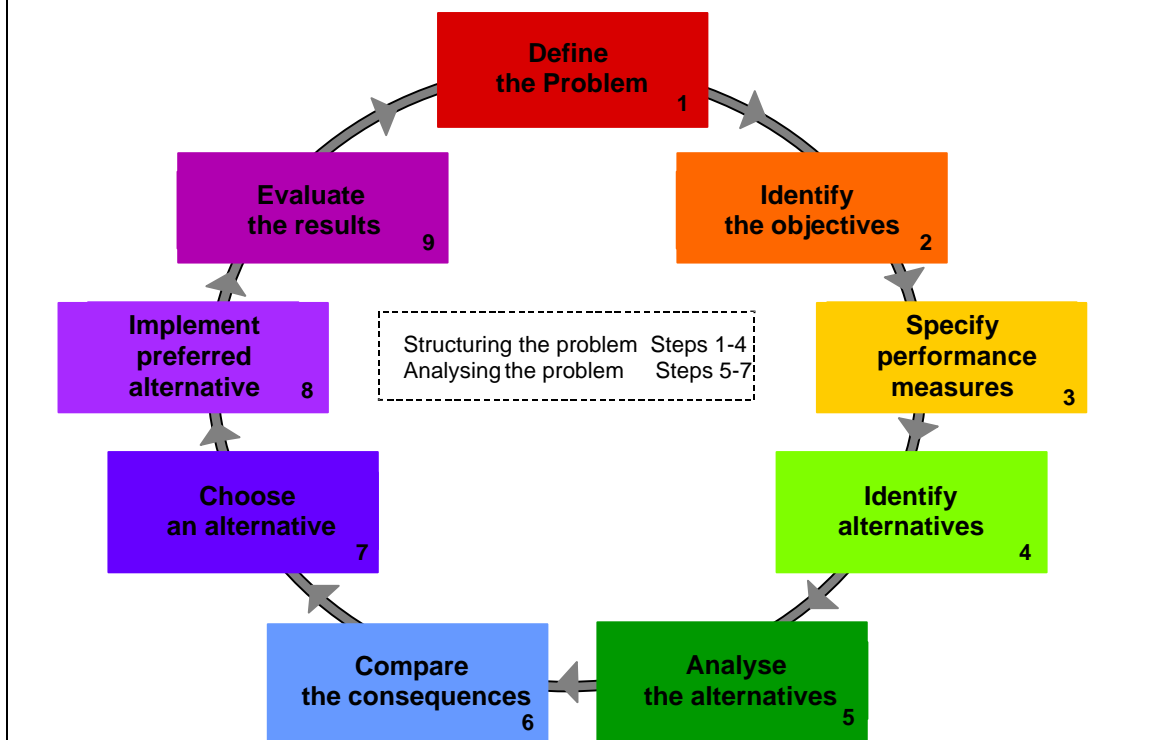


Multiple Criteria Decision Aid

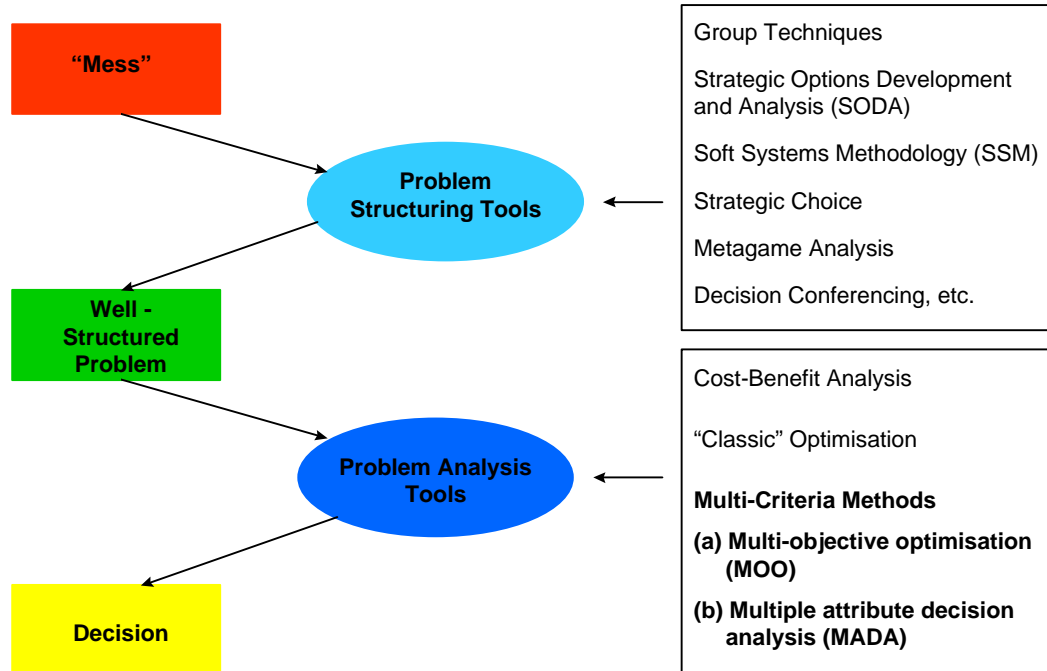
- Industrial decision making may occur at different **decision levels** namely **strategic, tactical and operational**.
- Decisions made at different decision levels differ in **complexity**, level of **uncertainty**, and the nature of **stakeholder involvement** required to ensure that the decision making processes are efficient, transparent and equitable.
- The aim of **decision support** is to assist decision makers to make decisions that are consistent with their values, goals and preferences. **Decision Analysis** provides both tools and a framework for the integration of these tools and those from other disciplines to create of an overall strategy for decision support.

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The Decision Analysis Cycle



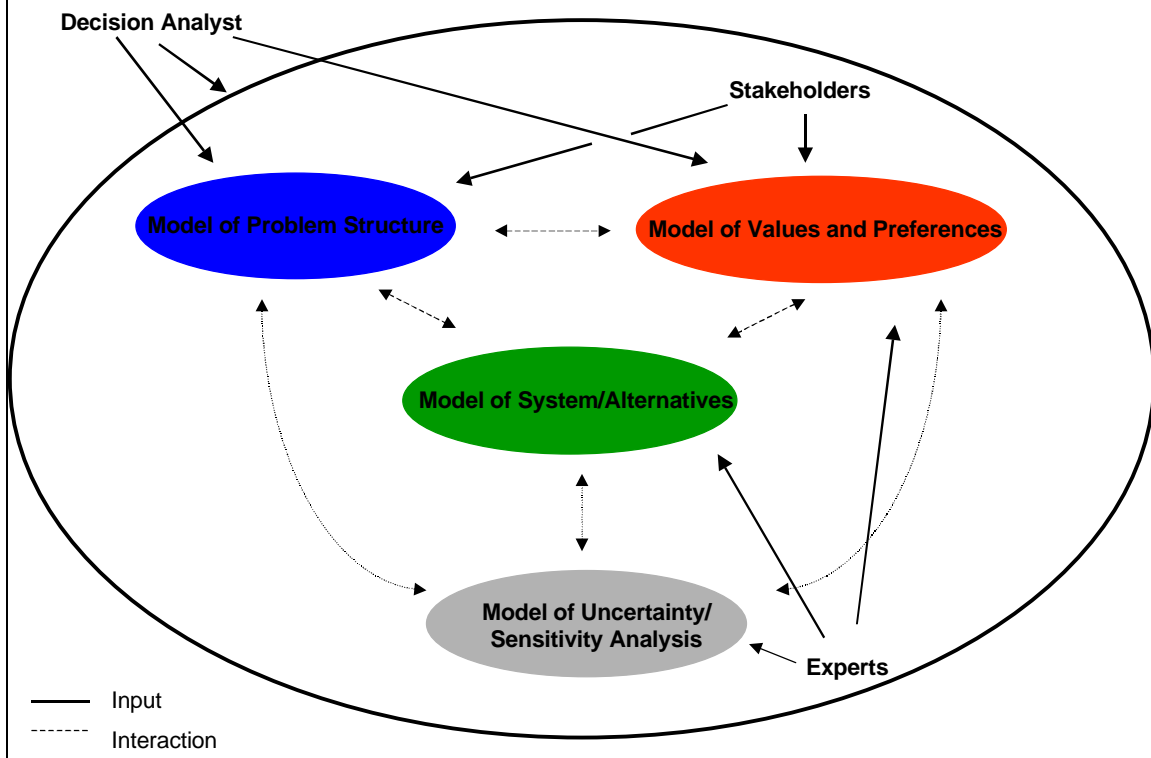
Tools to Aid in Problem Structuring and Analysis



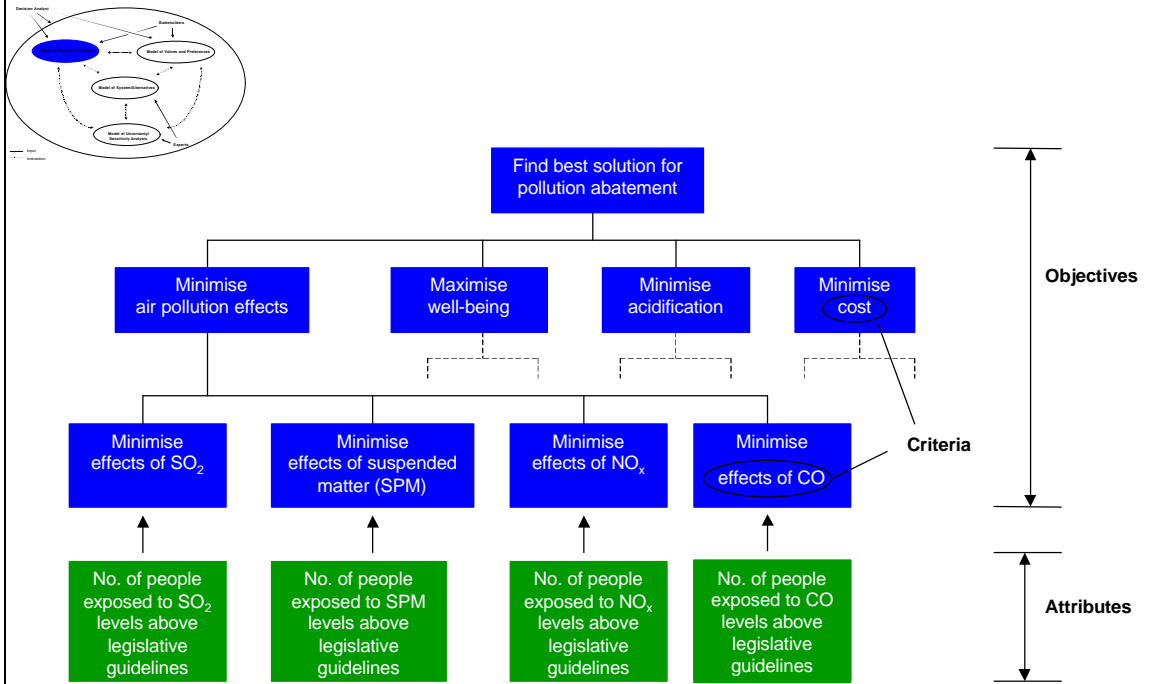
Decision Analysis Methodology

- Different stakeholders may have different **objectives** that need to be satisfied in a particular decision context.
- To facilitate decision making these objectives may be structured in an **objectives hierarchy** or **value tree** which represents an agreed set of **criteria** used to evaluate the set of alternatives under consideration.
- Each criterion can be represented in terms of some measurable **attribute(s)** which express the performance of the different alternatives relative to the particular criterion.

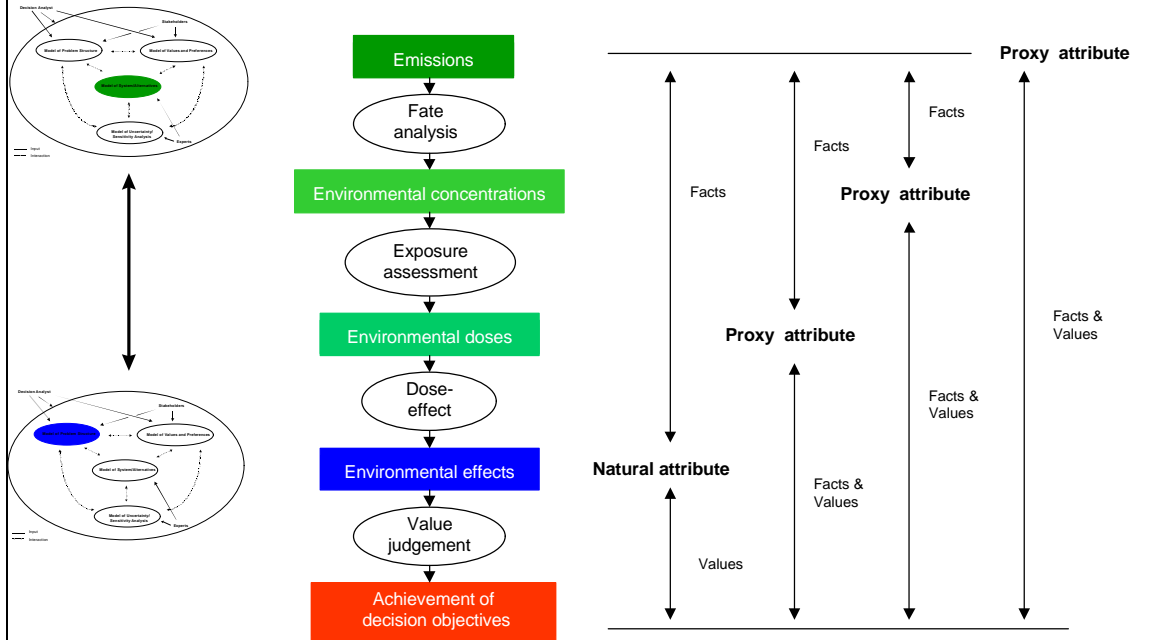
Decision Support Models



Models of Problem Structure



Natural and Proxy Attributes



Models of Preferences



Decision Table

	Criteria					
	g_1	\dots	g_j	\dots	g_n	
Alternatives	a_1	e_{11}	\dots	e_{1j}	\dots	e_{1n}
	δ	δ	\dots	δ	\dots	δ
	a_i	e_{i1}	\dots	e_{ij}	\dots	e_{in}
	δ	δ	\dots	δ	\dots	δ
	a_m	e_{m1}	\dots	e_{mj}	\dots	e_{mn}

Aggregation

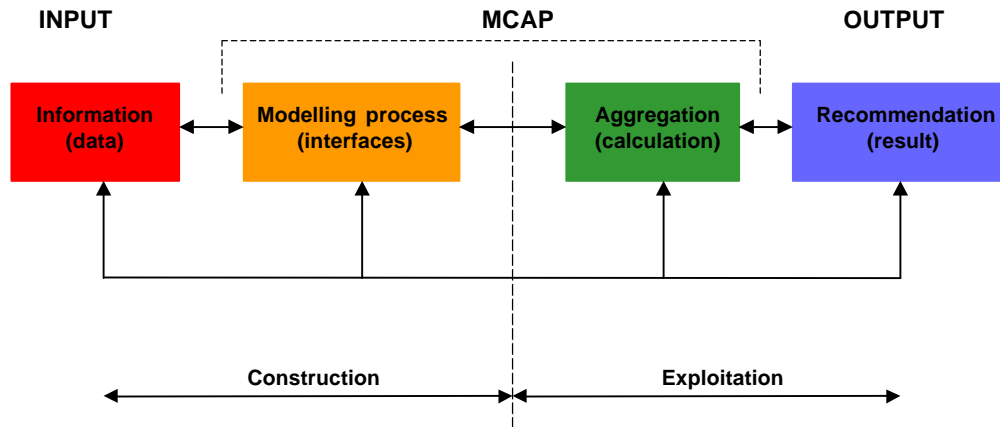
Performance Scores

Preference Relations

- $a \mathbf{P} b$ a is strictly preferred to b *Preference situation*
- $a \mathbf{I} b$ a is indifferent to b *Indifference situation*
- $a \mathbf{Q} b$ not being sure that $a \mathbf{P} b$ *Weak preference situation*
- $a \mathbf{R} b$ a and b are incomparable *Incomparability situation*

Multiple Criteria Decision Aid

Schematic Representation

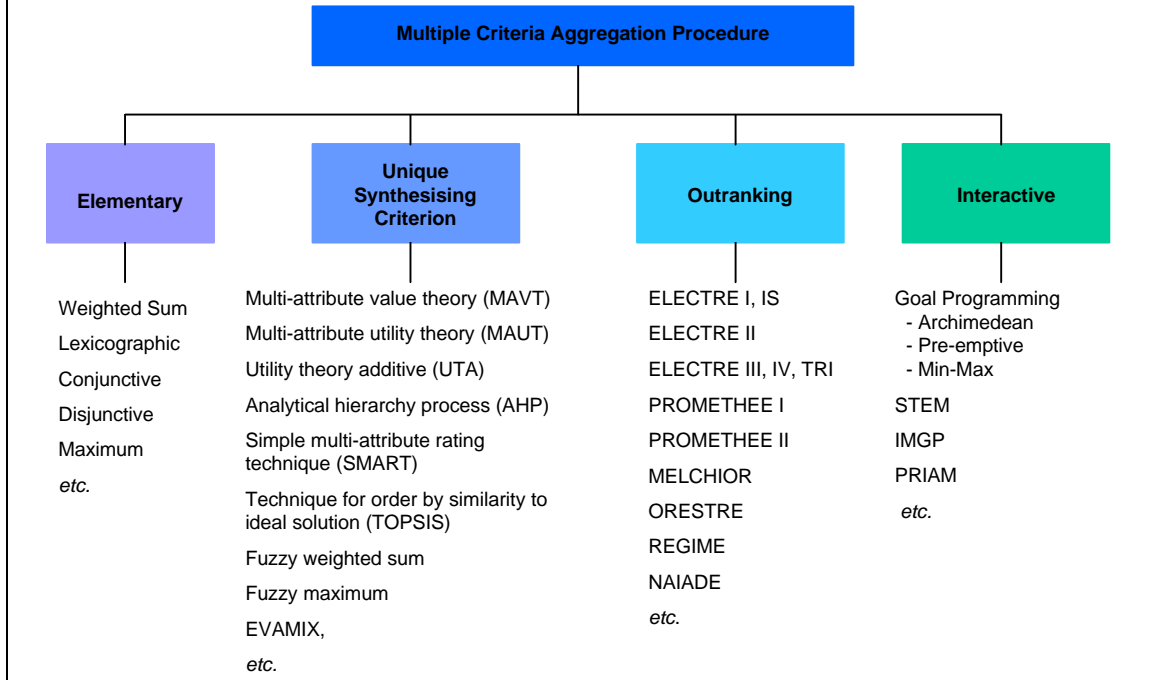


MCAP = multiple criteria aggregation procedure

Based on Guitouni and Martel 1998

Multiple Criteria Decision Aid

Multiple Criteria Evaluation Methods



Single Synthesising Criterion Approaches

● Performance Aggregation - Compensatory

	g_1	g_2	g_j	g_n
a_i	e_{i1}	e_{i2}	e_{ij}	e_{in}
a_j	e_{j1}	e_{j2}	e_{jj}	e_{jn}
a_n	e_{n1}	e_{n2}	e_{nj}	e_{nn}

$$g(a_i) = V[g_1(a_i), g_2(a_i), \dots, g_n(a_i)]$$

where a_i is an alternative i
 g_j is the criterion j
 V is the aggregation function
 g is the single synthesising criterion

● Methods in Common Use

- Multi-Attribute Value Function Theory (MAVT) (Keeney and Raiffa, 1976)
- Multi-Attribute Utility Function Theory (MAUT) (Keeney and Raiffa, 1976)
- Analytic Hierarchy Process (AHP) (Saaty, 1980)

Multi-Attribute Value Function Theory (1)

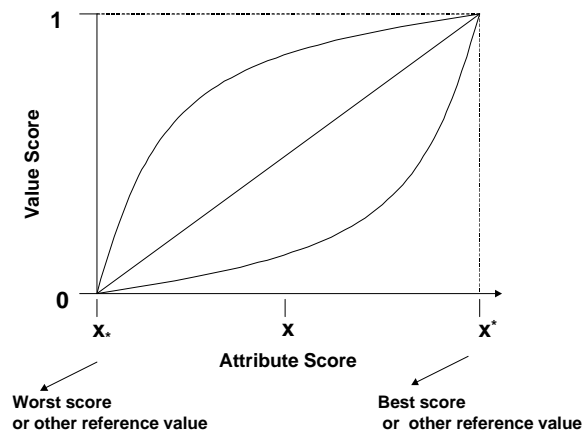
- Value Functions

- mathematical representations of human judgements
- translate the performances of the alternatives into a value score which represents the degree to which a decision objective is achieved

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Multi-Attribute Value Function Theory (2)

- Aggregation

- most commonly used aggregation function - **Simple Additive Weighting**

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$$V(a_i) = \sum_{j=1}^J (w_j v_j(a_i))$$

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where w_j is the **weight** of criterion j

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$v_j(a_i)$ is the **value** of alternative a_i in criterion j

- valid if criteria are preferentially independent (amongst other conditions)
 - weights
 - are **scaling constants**
 - have to be derived **with reference to the attribute ranges**
 - need to be elicited through questions which capture acceptability of **trade-offs**
 - e.g. "how many units of one specific attribute is worth how many of units of another specific attribute"

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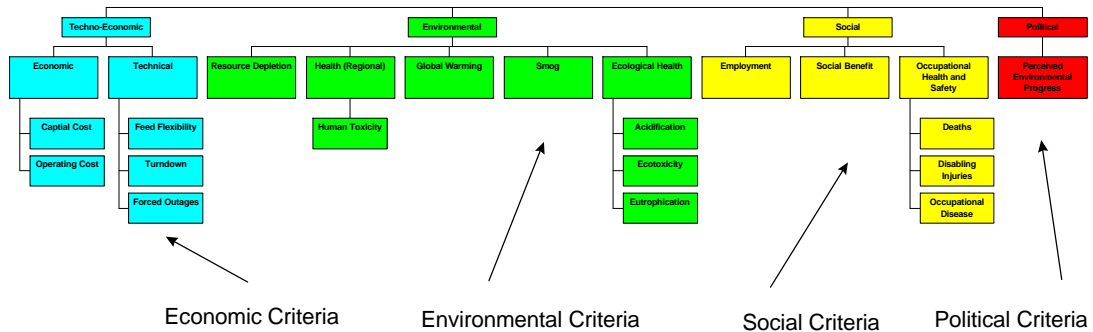
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Case Study

- **Early Stage of Project Life Cycle**
 - **Technology choice** for repowering of coal-based power generation facility
 - Options included various configurations of **pulverised fuel (PF)** and **fluidised bed combustion (FBC)** systems
- **Objectives Hierarchy**



Multiple Criteria Analysis

1. Analytical Hierarchy Process

- Expert Choice Software

2. Value Function Analysis (linear value functions)

- Analytica Software

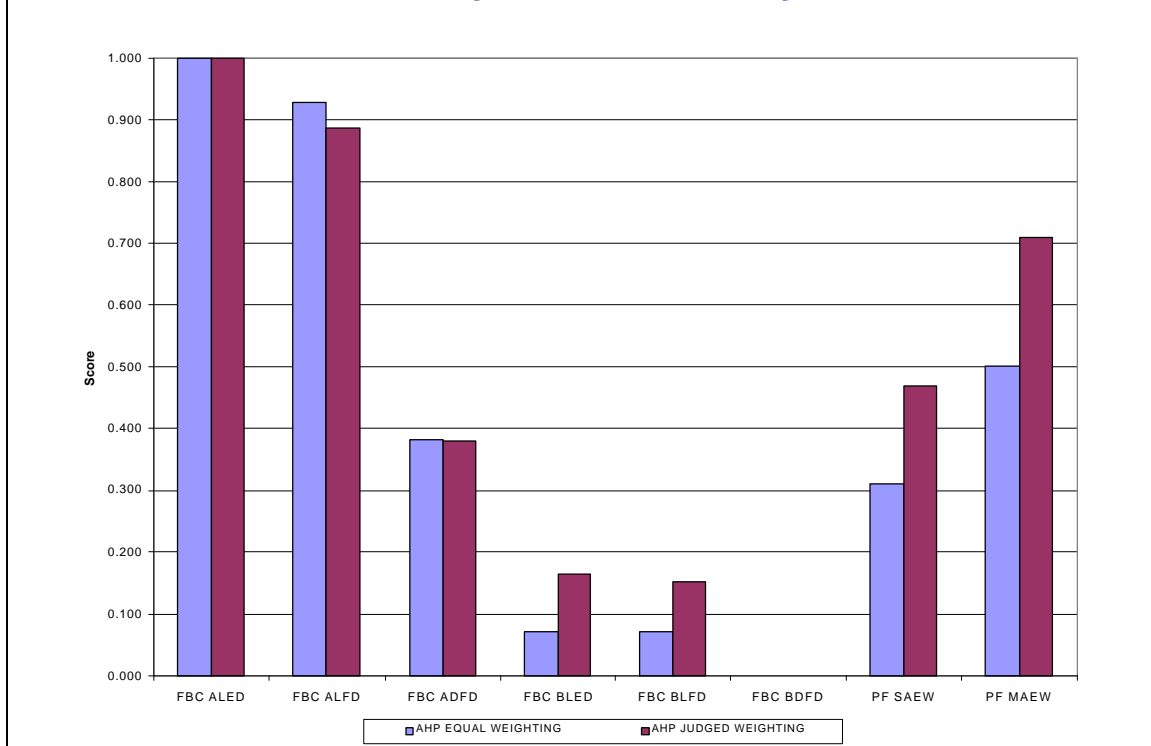
Comparison

- equal weighting for all criteria
- weights based on judgement of members of project team

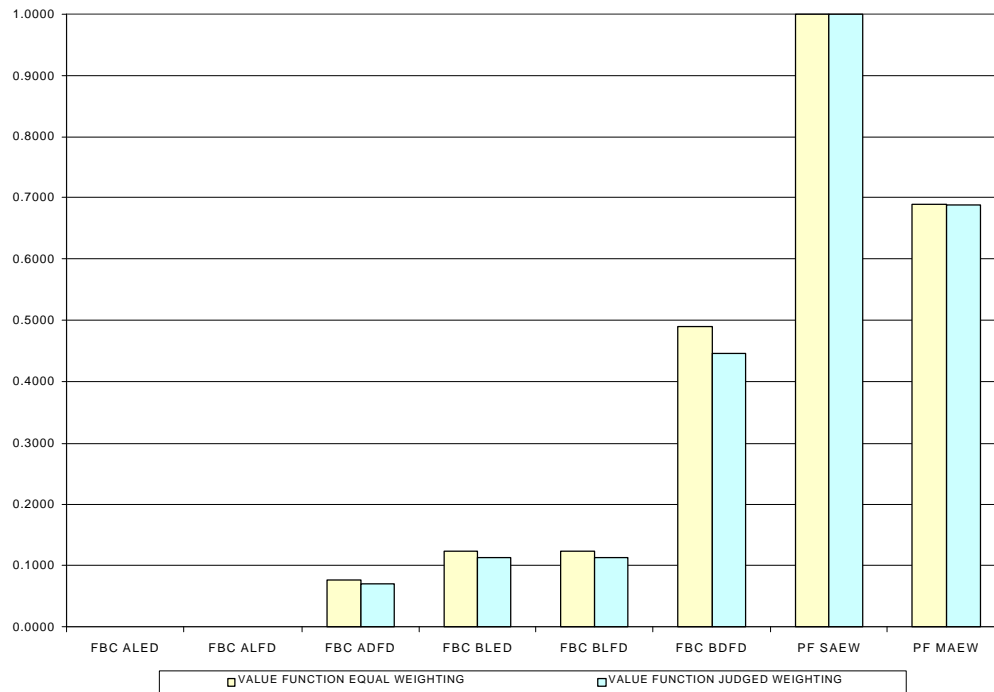
Uncertainty in Empirical Quantities

Source of Uncertainty	Example	Uncertainty Input
Statistical variation	Process monitoring data (water qualities, coal analyses, ash analyses etc.)	Standard or custom fit probability distributions
Subjective judgement	Using historical data trends to predict the future	Scenario analysis
Variability	Sulphur and ash content of coal, raw water quality, energy demand	Standard or custom fit probability distributions
Inherent randomness	Rainfall, evaporation	Standard or custom fit probability distributions
Disagreement	Background LCI data from various sources, combustion factors	Scenario analysis, uniform distributions
Approximation	Moisture retention on ash, % rainwater to surface run-off	Uniform or triangular probability distributions

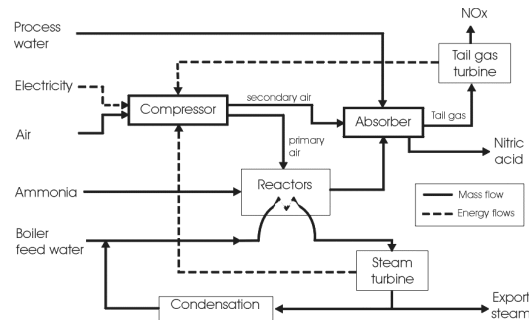
Results - Analytical Hierarchy Process



Results - Value Function Approach



Process Simulation

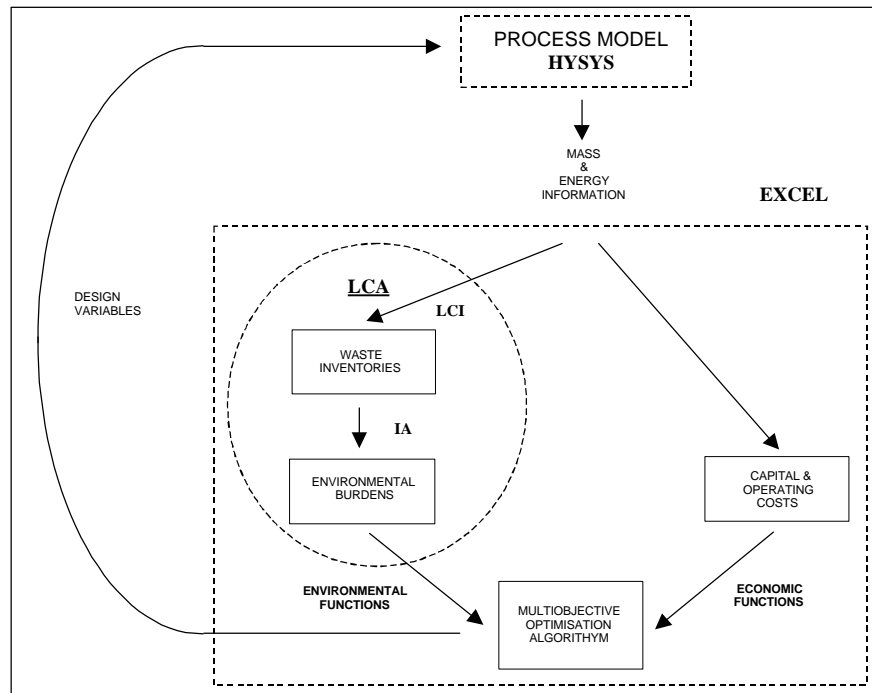


- Hysys is selected as the modelling package.
 - as it incorporates steady-state optimisation
 - is extendable to include dynamics
 - and readily interfaces with third party packages (including advanced control and commercial Distributed Control Systems DCS).

Framework

- Incorporate LCA Methodology with a Process Simulation Package (HYSYS).
- Use the combination to formulate objective functions for both environmental and economic attributes of the process.
- Use multi-objective tools to expose the degree of satisfaction of all objectives, and the tradeoffs implicit in the adoption of any preferred operating environment.
 - Multiple Objective Optimisation Technique used is goal programming.

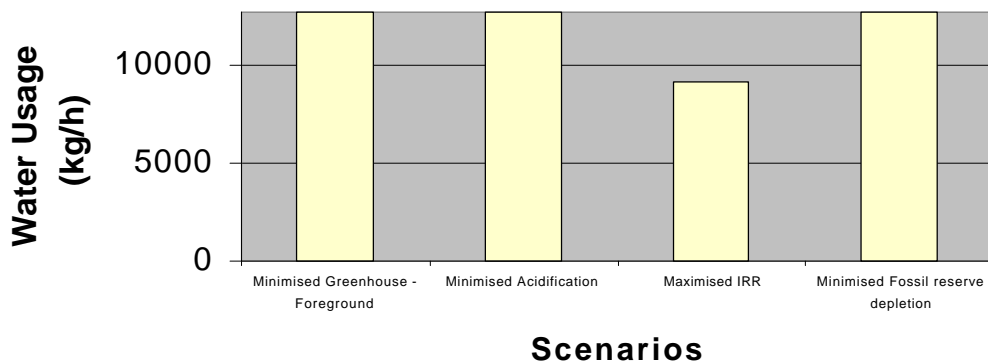
Methodology



Results

Consideration of Key Process Features

eg. Comparison of Water Usage for Satisfaction of Individual Objectives.



Ongoing Research

- Expand the Process Simulation boundaries to include background processes.
 - Include upstream processes in the simulation such as Ammonia Synthesis.
- Investigate incorporation of alternative Technology Options into the Process Flow-Sheeting Simulation.
- Investigate other methods for solving Multi - Objective Optimisation Problems.

Speaker Biography: Jim Petrie

Department of Chemical Engineering, University of Sydney
Shell Professor of Environmental Engineering & Director of Research

Present: Life Cycle Assessment, Environmental Decision Making and Management Systems, Design of Cleaner Technologies for the Process Industries, Waste Management

Previous: Associate Professor and Director of Environmental Process; Engineering Research Group; University of Cape Town, South Africa

Education

Chemical Engineering degrees from Cape Town and Houston, TX

Jim's main research interests are in the field of Life Cycle Assessment, Environmental Decision Making and Management Systems, Design of Cleaner Technologies for the Process Industries, and Waste Management. He has been a leading exponent of the role of LCA in Process Design and Impact Assessment. Some current research projects include:

- X Development of Decision Support Frameworks for Effective Environmental Management in Coal-based Power Generation
- X Managing Uncertainty in Environmental Decision Making
- X Data Management/Reconciliation for LCA - Spatial and Temporal issues
- X Integration of Environmental Management Tools
- X Industrial Symbiosis Network Analysis of Small and Medium Scale Enterprises
- X Environmental Assessment of the Australian Minerals industry
- X Prediction of Leachate Generation in Solid Waste Landfills
- X Optimization of Precipitation/Dewatering of Metal Hydroxides in Aqueous Effluents
- X Sulphur Management in the Minerals Industry

He has consulted widely for the Process Industries in South Africa and Australia, in particular the area of technology assessment as part of the Environmental Impact Assessment process.